Center Independent Research & Development: LaRC IRAD

High power density metal junction thermoelectric (TE) power generators

Completed Technology Project (2015 - 2016)

Project Introduction

High efficiency direct energy conversion is still a daunting challenge. The efficiency of state-of-the-art, semiconductor based thermoelectrics (TE) is in the range of only about 7~10% efficiency. The poor performance of conventional TE devices is due to the fundamentally limited potential well that is intrinsically determined by the population of doping materials. Developmental efforts in TE materials have so far only focused on lowering thermal conductivity in order to increase the figure of merit. Implicitly, this practice also lowers the overall energy flow through the TE system, resulting in low power density. A new approach based on metallic junctions will be implemented in this project to enhance thermoelectric performance beyond the state-of-the-art limit of the conventional concept and approach.

The performance of conventional TE devices is determined by the figure of merit (ZT): $ZT = S^2\sigma T/k$ (S: Seebeck coefficient, σ: electrical conductivity, k: thermal conductivity, and T: temperature). It must be noted that this figure of merit relates to the fundamental performance of the thermoelectric domain, and not necessarily to actual power delivered by a thermoelectric generator. The challenge in developing conventional thermoelectric materials with enhanced performance is being able to engineer the thermal and electrical parameters separately. Research to date has focused on morphological design and nanometer sized structures to lower thermal conductivity (k) in order to improve ZT. The reduction of the lattice contribution to the thermal conductivity directly improves ZT, and can be achieved through nanostructural design. However, lowering the thermal conductivity by introducing nanostructured dislocations and boundary conditions for phonon scattering, which disrupts the thermal transport, has not improved the figure of merit as anticipated. More importantly, these physical dislocations have not enhanced the power delivery of the thermoelectric devices.

This is largely due to a fact that lowering the thermal conductivity also reduces heat flow into a TE domain. Since the initial loading of thermal energy into a domain is substantially reduced by lowered thermal conductivity, there is a reduction in thermal energy in the domain to be converted into power. This is why the conventional TE principle has NOT worked favorably, despite the expenditure of significant resources and enormous effort. The charge carrier density in semiconductor-based TE materials is limited to the electron densities of 1 C/cm^3.

The aim of this project is to develop a new TE concept based on metal junctions, which will substantially increase the TE efficiency and power density resulting in substantially increased power delivery by TE generators. Metals have intrinsically high electron densities >10^3-10^4 C/cm^3, which is several orders of magnitude higher than the best semiconductors. Metal junctions are also easier to make than semiconductor junctions, which need an additional doping process. These factors combine to enable the fabrication of high efficiency, high power density energy conversion systems at reasonable cost.

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The actual power and power density delivered by the thermoelectric generator, rather than ZT, is going to be the target metric in this study. The power density predicted for metal junctions TE will be greater than thermoelectrics with semiconductor junctions for the reasons given above.

Anticipated Benefits

Long duration human exploration missions as well as robotic missions to the far and dark edges of the solar system will benefit from this technology as the electrical power for spacecraft can be obtained by converting the heat generated by the decay of radioisotopes such as the conventionally used Pu-238 and other radioisotopes into electricity. For these reasons, new types of RTG assembled from the combination of the metal junction TEs proposed in this study and new radioisotope materials would be highly beneficial. The enhanced density with which these junctions can be packed would also be beneficial for spacecraft by providing small and lightweight power modules.

Enhanced solar cell performance by a tandem structure of metallic junction TE will benefit from this technology. Essentially all the NASA missions to the outer planets need RTG based power in order to be able to conduct robust science operations.

As evidenced by the Curiosity rover, more capable missions on Mars can greatly benefit from the use of RTG power and the year (sol) round and around the clock operations which RTGs enable.

New classes of NASA probes to explore the scientifically enticing oceans on the moons of Jupiter and Saturn will all require RTG power.

A tandem structure of solar cell and metallic junction TE to increase the energy conversion efficiency is beneficial for satellites.

As commercial space moves towards more ambitious targets such as asteroid mining and missions to the dark side of the moon, the role and importance of enhanced power generation capabilities will only increase.

Organizational Responsibility

Responsible Mission Directorate:

Mission Support Directorate (MSD)

Lead Center / Facility:

Langley Research Center (LaRC)

Responsible Program:

Center Independent Research & Development: LaRC IRAD

Project Management

Program Manager:

Julie A Williams-byrd

Principal Investigator:

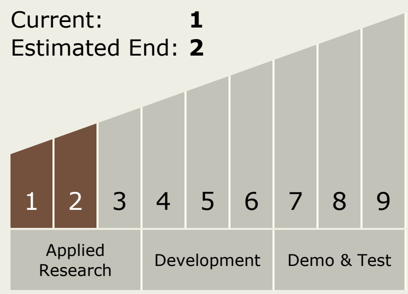
Hyun Jung Kim

Co-Investigator:

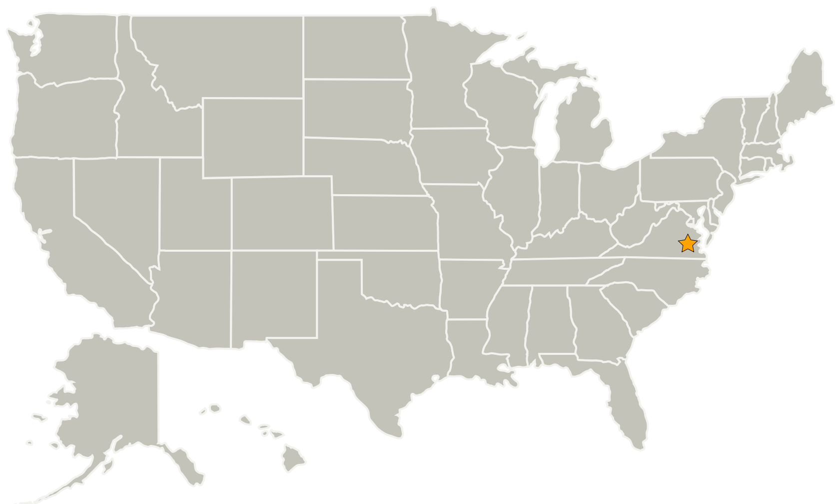
Sang H Choi

Technology Maturity (TRL)

Start: **1**
Current: **1**
Estimated End: **2**



Primary U.S. Work Locations and Key Partners



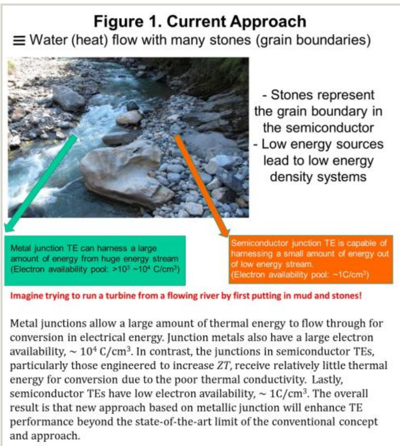
Organizations Performing Work	Role	Type	Location
★Langley Research Center(LaRC)	Lead Organization	NASA Center	Hampton, Virginia
National Institute of Aerospace	Supporting Organization	Academia	Hampton, Virginia

Technology Areas

Primary:

- TX12 Materials, Structures, Mechanical Systems, and Manufacturing
  └ TX12.1 Materials
    └ TX12.1.6 Materials for Electrical Power Generation, Energy Storage, Power Distribution and Electrical Machines

Images



Current Approach
Imagine trying to run a turbine from a flowing river by first putting in mud and stones.
(https://techport.nasa.gov/image/19134)